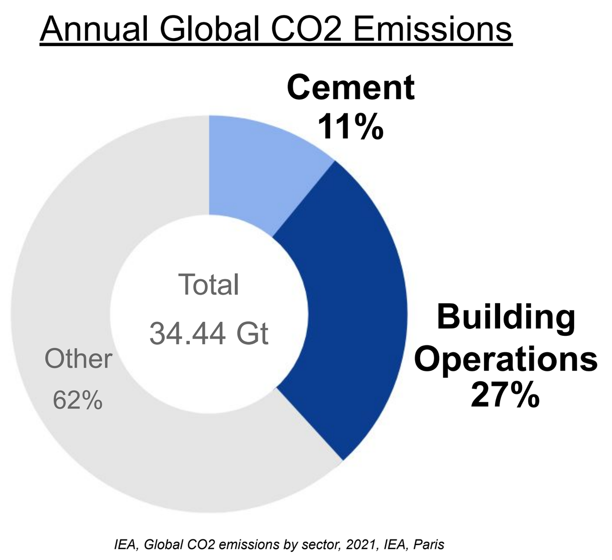
Thermal Performance of Nanoparticle Reinforced Enzymatic Construction Materials

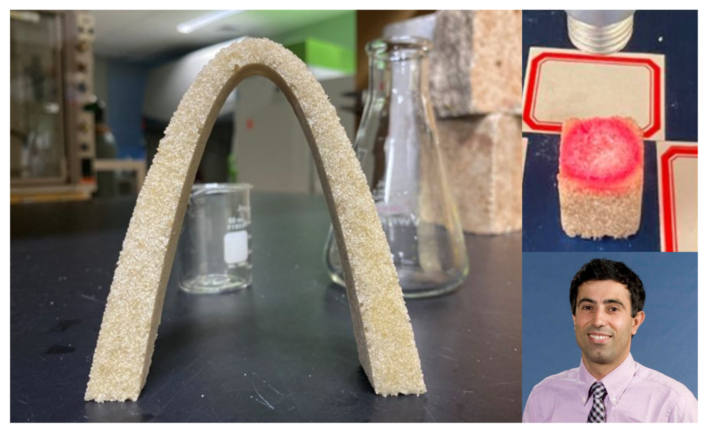
Georgy Zhukov (AREN), Anne McNamara (AREN)

Advisor: Professor Steven Van Dessel (AREN), Professor Nima Rahbar (CE)

Overview

Building operations and cement manufacturing are both responsible for 38% of the total CO_2 emissions worldwide (Architecture 2030, 2022). Concrete is the second most used material in the world, with water holding first. Energy consumption and associated CO_2 emissions must be diminished to put the United States on track for the Federal Sustainability Plan (The Executive Order 14057).





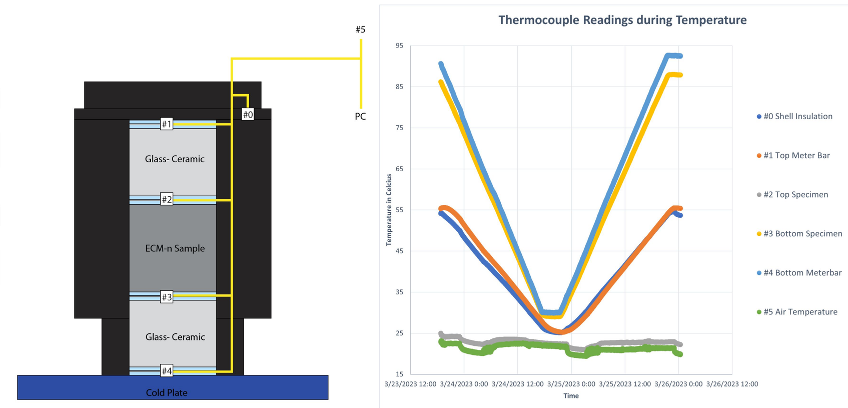
The **Enzymatic Construction Material with nanoparticles** (ECM-n) is a new carbon-negative construction material alternative to concrete (Wang, Rahbar, et al., 2022). Despite its remarkable compressive strength, ECM-n's best virtue is innovative photothermal properties.

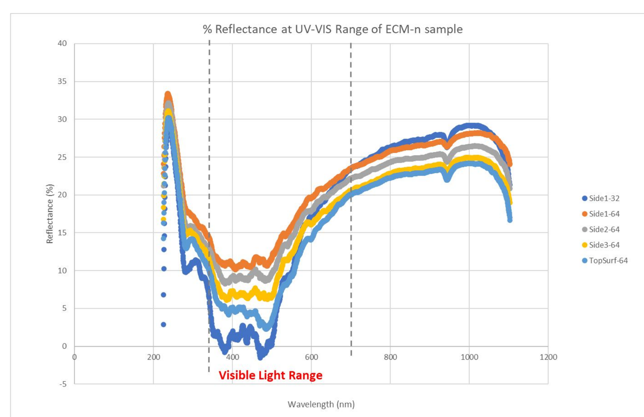
Goal

Design and deliver comprehensive analysis of the photothermal heating system with ECM-n.

Experiments

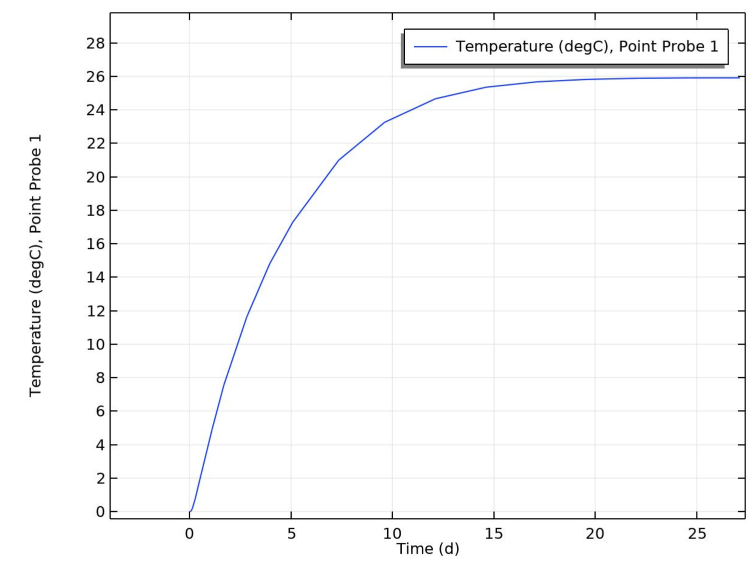
Thermal Conductivity:
Testing with a guarded longitudinal comparison calorimeter (GLCC) and temperature readings from thermocouples produced the material's **thermal conductivity.**





Optical Absorbance and Reflectance:
Testing with the UV-VIS range spectrometry instrument produced the ECM-n's **reflectance**. The IR range spectrometry gave both absorbance and reflectance.

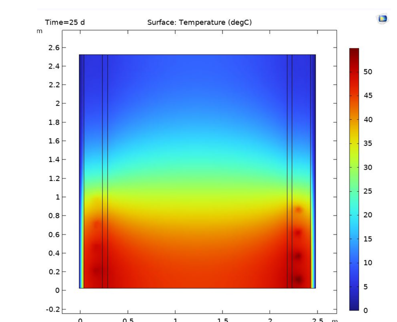
Energy Modeling

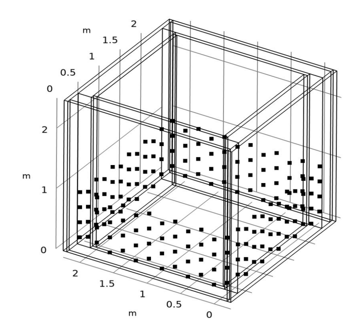


The COMSOL model assumes **steady-state heating** conditions per constant power input. The following variables were used:

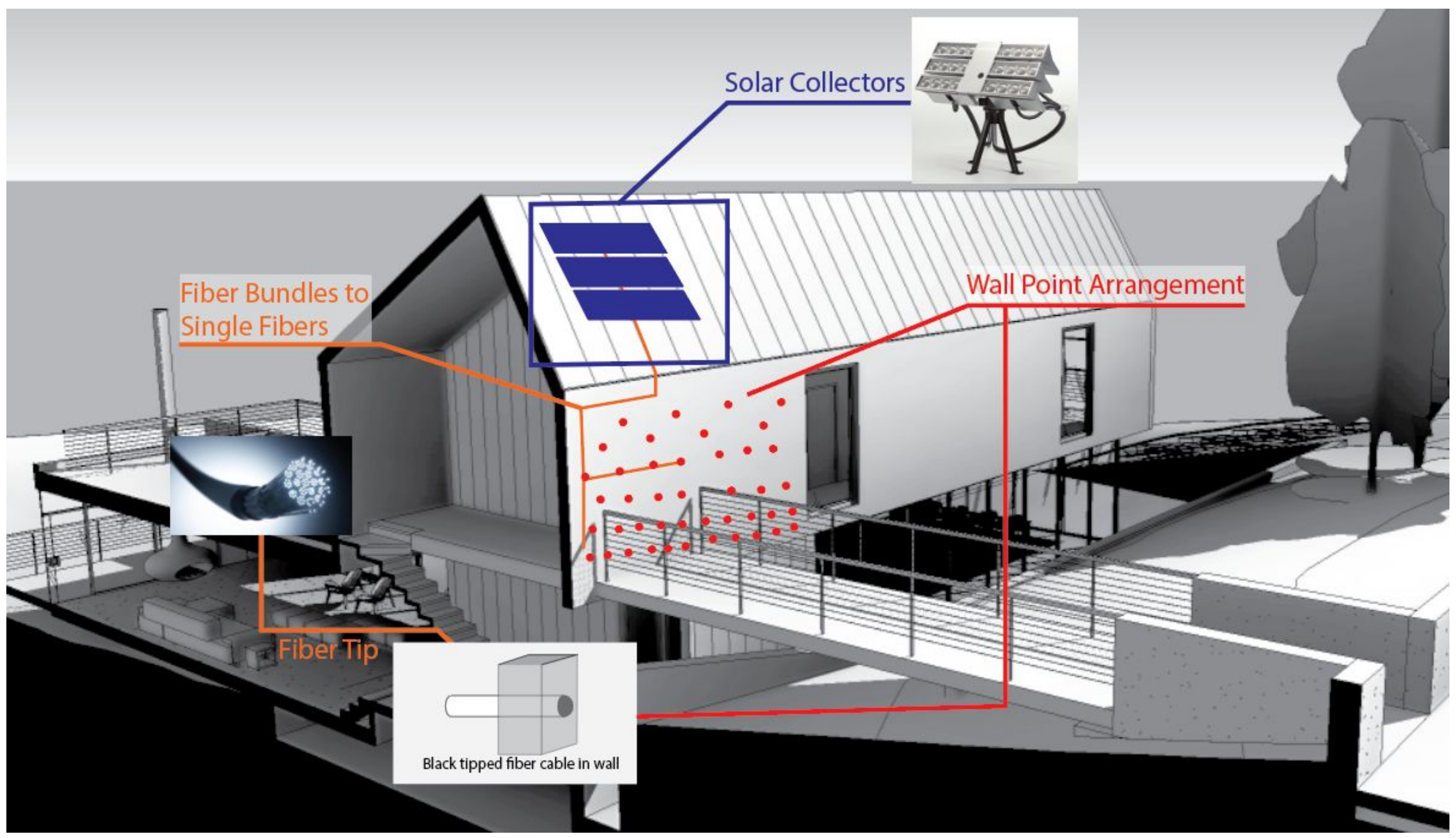
- Temperature (°C)
- Heat Flux: $q = -k * dT/dx$

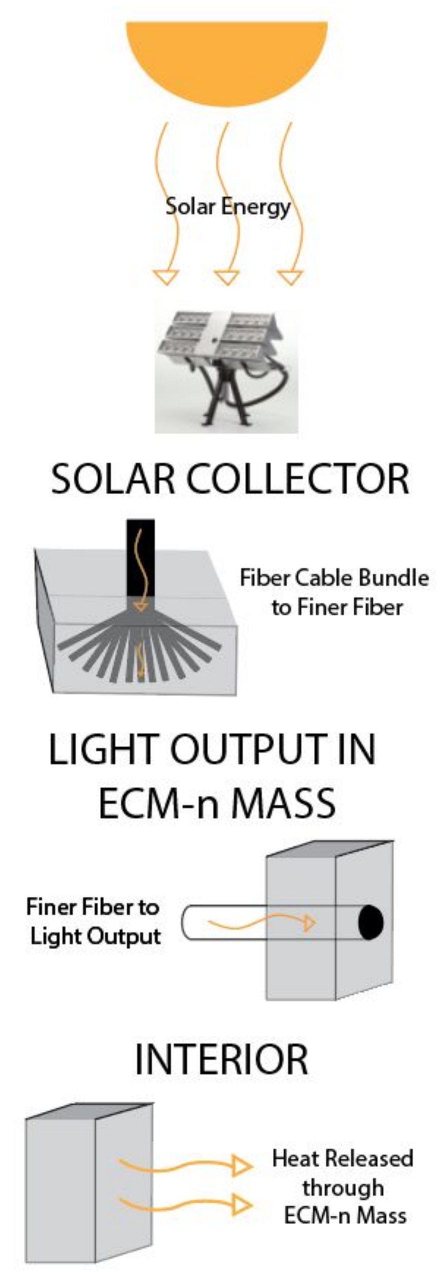
Surface integration results from COMSOL software for heat flux and temperatures showed how much power and time is needed to reach steady-state conditions inside the room. Heat points are located in the lower half of the walls to promote convective air circulation. Model's initial temperature is 0°C and a goal temperature gradient is 26°C.





Passive Photothermal Heating System Design





Results

- Analysis of experimental data collected from Guarded Calorimeter determined the ECM-n's thermal conductivity to equal **1.5688 W/m*K.**
- Optical experiments showed peaks at various wavelengths, singling out **high absorbance** at the wavelength range of **350-500 nm.**
- Thermal performance simulation showed that a room built with ECM-n that is encased in XPS insulation needs **440 Watts** of power to be heated to 26°C.

Conclusion

The photothermal radiative heating system with ECM-n needs only **37.5 square meters of solar collectors installed to heat 100 square meters of interior space.** The design pulls directly from solar power, a free renewable energy source, providing sustainable "off-the-grid" heating energy to buildings. No solar panels are used in the system, so the electrical energy generation process is negligible. It therefore increases the overall versatility of the system by omitting the installation of electrical equipment.